RESEARCH COMMUNICATION

Relations between Radiotherapy Resources and Breast Cancer Patient Survival Rates

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Abstract

In Japan, the number of patients that have been treated with radiotherapy (RT), particularly those with breast cancer, has increased in the past decade, and is expected to double in the next decade. There is, however, a shortage of RT resources, particularly personnel, which represents a social problem. The shortage of RT resources might cause a difference in survival rate among treated patients. This study analyzed the characteristics of RT resources in RT facilities from Osaka based on the Japanese Society for Therapeutic Radiology and Oncology (JASTRO) database with principle component analysis and cluster analysis. In addition, the relation between RT resources and treatment outcome of breast cancer patients was investigated by linking together Osaka Cancer Registry (OCR) and JASTRO data via a stratified key cord. By using the linked dataset it was shown that the prognosis of breast cancer patients was highly correlated with the scale of RT resources available at the RT facilities collaterally. From cluster analysis, four groups were identified based on RT facility information. The breast cancer survival rates for localized stage patients obtained in classified hospital groups showed a similar pattern, however, large differences (up to 20%) were seen in regional stage patients. Additional findings were: RT facilities with less than 1 radiation oncologist had the poorest outcome; RT was performed primarily at University hospitals; and differences in RT resources within the RT facilities had an effect on breast cancer patient prognosis in Osaka, Japan.

Keywords: Radiotherapy resources - breast cancer - survival rate - JASTRO

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Introduction

Current cancer treatment consists of surgery, chemotherapy and radiotherapy (RT). The number of patients receiving RT has doubled in the past 10 years and is estimated to again double in the next 10 years (Shibuya et al, 2005). There is currently a shortage in RT personnel, particularly radiation oncologists and medical physicists (Teshima et al, 2008). There has been strong growth in the use of RT, and an expansion in personnel and maintenance and an improvement in providing treatment will be necessary for implementing advanced RT(Ishikura, 2008). There has thus far been no information available on structural and resource information of RT facilities and its relation to patient prognosis.

We utilized two databases which separately collected structural information from RT facilities and patient prognosis information. The first database, collected by the Japanese Society for Therapeutic Radiology and Oncology (JASTRO), contains structural conditions of domestic RT facilities. The other database is the regional cancer registry, which contains information on patient prognosis.

Various additional databases that contain many types of information have also been created for various uses. Restrictions in protecting individual patient information have made it difficult to link databases or import information from remote databases. A method to link databases would allow analysis of more than one database at a time and thus identify and evaluate new relationships between the data contained within. In this study, a database linkage method was proposed and linked datasets utilized to analyze the characteristics of RT resources. And their effect on the prognosis of breast cancer patients was analyzed with a linkage dataset. We reported a possibility of RT resources and breast cancer patient survival rate.

Materials and Methods

The JASTRO database includes numerous items such as the type and number of treatment equipment, the

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annual number of RT patients, and the annual number of total cases, stratified by afflicted organ, that underwent treatment at each RT facility. In 2003, 726 facilities nation-wide responded to this survey, at a response rate of 100% (Shibuya et al, 2005). We selected 19 items from more than 100 items of JASTRO database which were employed for this study. These 19 items reflect personnel resources and treatment equipment as well as treatment performance, and include: "Number of beds", "Number of radiological beds", "Number of full-time radiation oncologists (ROs)", "Number of part-time ROs", "Time devoted to RT by full-time ROs (FTE of full-time ROs)", "Time devoted to RT by part-time ROs (FTE of part-time ROs)", "Number of full-time radiological diagnosticians", "Number of part-time radiological diagnosticians", "Number of radiological technologists", "Number of part-time physicists", "Number of radiological nurses", "Number of radiological assistants and administrators", "Number of linear accelerator (LINAC) devices", "Number of other treatment devices (gamma knives, particle beams)", "Number of X-ray and CT scanners", "Number of MRI scanners", "Number of new radiation patients", "Total number of irradiated target organs" and "Number of breast cancer patients".

In 2003, 48 RT facilities in Osaka participated in the JASTRO survey. "Time devoted to RT" refers to the proportion of time occupied exclusively by RT, where a value of 1 represents 40 hours of work in a single week. Time was added across full- or part-time ROs at each RT facility.

The Osaka Cancer Registry (the OCR database) is the largest population based cancer registry in Japan and has been collecting information from cancer patients since 1962. Information collected by the registry includes patient age, sex, type of treatment, date of diagnosis, data of last contact, and other supporting information.

We produced a dataset consisting of 19 items from the JASTRO database and the extracted OCR dataset and linked following methods:

Extraction of RT resource items by principal component analysis

Principal component analysis is a method that explains the covariance between two or more variables by small number of synthesis variables. We attempted to combine the 19 items into a smaller number of variables using principal component analysis and deselecting variables which were inappropriate.

Classification of RT facilities by cluster analysis

RT facilities in Osaka were classified into several clusters based on the various characteristics and properties of their RT resources with items that extracted using principal component analysis. The RT facilities were stratified based on cluster analysis results. The JASTRO and OCR datasets were linked by the use of a common code functioning as a key code, which was the RT facility code of the JASTRO dataset and the medical institution code of the OCR dataset. The key code was afterwards deleted to protect individual patient information and the linked dataset was received from the OCR.

Comparison of treatment outcome from 5-year survival rates

Based on the linkage dataset, 5-year breast cancer survival rates were calculated using the Kaplan-Meier method on each cluster.

From the OCR database, information from female breast cancer patients diagnosed from 1993-1999 was extracted to a prognosis dataset. Patient cancer stage was restricted to either localized or regional and patients had undergone surgery and irradiation treatment in the surveyed RT facilities in 2003. A total of 1,907 patients were identified. The following patients were excluded prior to extraction of the prognosis dataset: 1) those registered solely on the basis of death information 2) those that were discovered initially from a death certificate 3) those registered solely on the basis of a remission report and 4) those with multiple cancers.

Results

Extraction of RT resource items by principal component analysis

A principal component analysis was conducted utilizing 19 items extracted from the JASTRO database. Results shown in Table 1 indicate that there were 5 principal components that had more than 1 eigen value. The eigen values of the first through fifth principal components were 8.19, 1.95, 1.63, 1.56 and 1.17, respectively. The proportion of the first principal component was 43.1% and the cumulative proportion up to the fifth principal component was 76.3%. The first component was able to explain more than 40% of the RT resources for all RT facilities. Examination of the principal components after the further varimax rotation revealed that the first principal component comprised 11 items that included the "Number of full-time ROs", "FTE of full-time ROs", "Number of new patients", "Number of X-rays and CT scanners" and "Number of patient radiological beds". By analyzing variable scores of the first principal component, "Number of full-time ROs" and "FTE of full-time ROs" scored the highest and the variable score of "Number of X-rays and CT scanners" was found to be higher than "Number of LINAC devices". The first principal component comprised both the availability of personnel and the treatment equipment.

The second principal component was comprised of 3 variables; "Number of radiological nurses", "Number of other treatment devices" and "Number of radiological technologists". The third principal component through to the fifth were comprised of 1, 2 and 2 variables, respectively. From the magnitudes of the eigen values alone, the 11 variables that comprised the first principal component were thought to have considerably effective representation as RT resource indices of the RT facilities.

When results of RT facilities cluster analyses were compared with the 19 extracted items and 11 variables, the classification trees of the RT facilities were found to consist of 4 identical clusters with the exception of 1 classified facility. For this reason, 11 variables were used in the present study as the RT resource indices following cluster analysis.

Table 1. Results of Principal Component Analysis

Variable Principal component	First	Second	Third	Fourth	Fifth
Number of full-time radiation oncologist	**0.885**	-0.020	0.091	0.124	-0.158
FTE* of full-time radiation oncologist	**0.871**	-0.008	0.172	0.264	-0.121
Number of new patients	**0.821**	0.221	0.420	-0.022	-0.016
Number of X-ray CT scanners	**0.821**	0.117	0.184	-0.372	0.048
Number of beds for radiotherapy	**0.817**	0.145	0.280	0.050	0.136
Nnumber of total treatment cases	**0.808**	0.175	0.461	-0.041	-0.006
Number of total beds	**0.771**	0.075	0.131	-0.178	0.058
Number of MRI scanners	**0.748**	0.122	-0.037	-0.124	0.191
Number of linear accelerators	**0.717**	-0.397	0.289	0.114	0.089
Number of full-time doctors for diagnosis	**0.689**	0.105	-0.134	0.215	-0.045
Number of breast cancer patients	**0.687**	-0.007	0.547	0.062	-0.009
Number of nurses for radiotherapy	-0.070	**0.915**	0.190	-0.027	-0.010
Number of other treatment devices	0.489	**0.742**	-0.276	-0.130	0.000
Number of full-time technologists	0.393	**0.527**	0.471	0.251	-0.026
Number of assistants for radiotherapy	0.234	0.035	**0.756**	-0.045	0.052
Number of part-time doctors for diagnosis	-0.059	0.031	0.088	**0.791**	0.041
Number of medical physicists	0.090	-0.071	-0.077	**0.790**	0.068
FTE of part-time doctors	-0.024	-0.007	0.118	-0.021	**0.867**
Number of part-time doctors	0.060	-0.017	-0.072	0.138	**0.865**

*full-time equivalent

Table 2. Mean and Standard Deviation for 11 Treatment Resources for Separate Clusters

		Cluster 1 (7 facilities)	Cluster 2 (16 facilities)	Cluster 3 (17 facilities)	Cluster 4 (5 facilities)
Workload	New patients	688.1 ± 149.1	298.4 ± 74.8	152.9 ± 63.2	110.9 ± 62.3
	treatment cases	851.1 ± 203.7	357.4 ± 85.9	177.4 ± 72.9	85.9 ± 74.4
	Breast cancer patients	126.2 ± 46.2	53.2 ± 12.7	31.8 ± 26.5	19.1 ± 27.7
Personnel	Full-time doctors	4.6 ± 1.7	1.6 ± 0.5	0.8 ± 0.8	0.7 ± 0.9
	FTE of full-time doctors	3.2 ± 1.1	1 ± 0.4	0.4 ± 0.4	0.4 ± 0.2
	Full-time doctors for diagnosis	13.4 ± 15.1	4.2 ± 1.1	2.4 ± 2.0	2.3 ± 2.7
Equipment	Total beds	975.4 ± 213.3	748.8 ± 58.3	560.4 ± 64.6	324.4 ± 33.4
	Beds for radiotherapy	14.6 ± 5.2	0.2 ± 1.0	0.6 ± 2.0	0.3 ± 0.4
	MRI scanners	2.9 ± 0.7	2.2 ± 0.4	1.6 ± 0.8	1.3 ± 0.4
	Linear accelerators	1.8 ± 0.4	1.4 ± 0.4	0.9 ± 0.3	0.8 ± 0.5
	X-ray CT scanners	4.9 ± 1.6	3.2 ± 0.7	2.5 ± 0.8	1.7 ± 1.1

Classification of RT facilities by cluster analysis

Utilizing 11 items, a cluster analysis of RT facilities showed that 48 RT facilities in Osaka could be broadly classified in two main clusters (Figure 1). Cluster 1 was composed of 7 RT facilities, which represented 5 University-affiliated hospitals, and 2 designated cancer care hospitals (as the University hospital-series group). A University-affiliated dental hospital was not classified in cluster 1. The other hospital groups could be classified into 3 remaining clusters.

In Japan, the Ministry of Health, Labor and Welfare designated specific cancer care hospitals to equalize cancer care services and in 2003, 10 cancer care hospitals were selected in Osaka. Despite their designation as cancer care hospitals with equal care services, they were found to be classified into various clusters. As a result of cluster analysis of RT facilities, 2 facilities that did not comprise a cluster group and 1 facility that was not classified in clusters were excluded following analysis.

Table 2 compares the previously identified 11 items among the 4 clusters. For personnel resources, the mean number of full-time ROs from each cluster was 4.6, 1.6, 0.8, and 0.3, respectively. RT facilities that comprised clusters 3 and 4 had a mean number of ROs <1. In addition, the time devoted to RT from the 4 clusters was 3.2, 1.0, 0.4 and 0.4 FTE, respectively.

For equipment, the mean number of LINACs from the 4 clusters was 1.8, 1.4, 0.9, and 0.8, respectively. In the medical institution groups that comprised clusters 1 and 2, institutions possessed on average one or more LINACs. For clusters 3 and 4, however, the mean number was lower than one. The mean number of diagnostic MRI

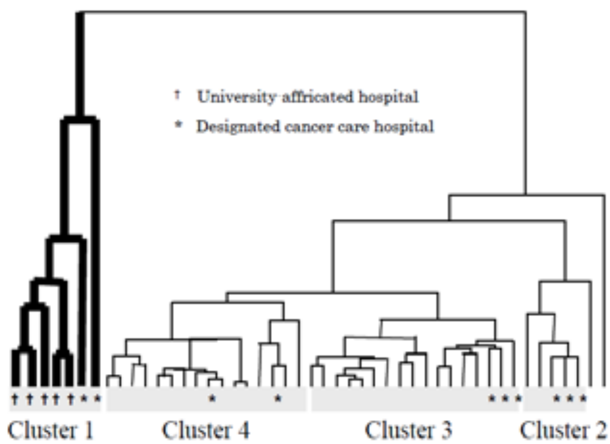

Figure 1. The Classification Tree of RT Facilities

Table 3. Patient Characteristics for Separate Clusters

		Cluster 1		Cluster 2		Cluster 3		Cluster 4	
Localize	n	447		386		240		159	
	Age ± SD	51.6	± 9.9	53.3	± 11.4	52.4	± 10.7	52.7	± 12.3
	Chemotherapy (%)	81	(18.1 %)	204	(52.9 %)	108	(45.0 %)	56	(35.2 %)
	Hormonal therapy (%)	362	(81.0 %)	227	(58.8 %)	175	(72.9 %)	121	(76.1 %)
	Death	17		10		15		12	
Regional	n	191		203		174		107	
	Age ± SD	50.7	± 10.6	52.1	± 10.3	52.3	± 10.6	53.9	± 11.3
	Chemotherapy (%)	151	(79.1 %)	176	(86.7 %)	155	(89.1 %)	84	(78.5 %)
	Hormonal therapy (%)	155	(81.2 %)	153	(75.4 %)	156	(89.7 %)	81	(75.7 %)
	Death	30		51		56		37	

scanners present in the 4 clusters was 2.9, 2.2, 1.6 and 1.3, respectively, while the mean number of X-ray CT scanners was 4.9, 3.2, 2.5 and 1.7, respectively.

The mean number of total beds from the 4 clusters was 975.4, 748.8, 560.4, and 324.4, respectively and the mean number of radiological beds was 14.6, 0.2, 0.6 and 0.3, respectively. RT facilities from cluster 1 have many beds used exclusively by the radiology department.

For treatment performance, the mean number of irradiated organs from the 4 clusters was 851.1, 357.4, 177.4, and 85.9, respectively and the mean number of breast cancer patients treated was 126.2, 53.2 31.8, and 19.1, respectively. Cluster 1 had accrued more than twice the treatment experience of cluster 2. Treatment experience decreased progressively from cluster 1 through cluster 4.

Comparison of treatment outcomes from 5-year survival rates

The 5-year survival rate was calculated for each cluster using the Kaplan-Meier Method (Figure 2).

Table 3 shows both localized and regional stage patient characteristics. The 5-year survival rates in patients with localized cancer in each of the 4 clusters was: cluster 1- 96.2%, cluster 2- 97.4%, cluster 3- 93.6%, and cluster 4- 92.3%. Patient prognosis in each of the clusters was relatively good at 5.1%, depending on the particular cluster (data not shown). A log rank test revealed significant differences between clusters 3 and 4, clusters 2 and 3, and clusters 2 and 4.

The 5-year survival rates of patients with regional cancer were: Cluster 1- 84.2%, Cluster 2- 74.5%, Cluster 3- 66.7%, and Cluster 4- 64.8% (Figure 2). Differences in survival rates were seen between specific clusters; the highest survival rate was in cluster 1, at 83.9%, while the lowest was in cluster 4, at 61.5%, a difference of approximately 22%. In addition, a log rank test revealed significant differences between cluster 1 and the other remaining clusters.

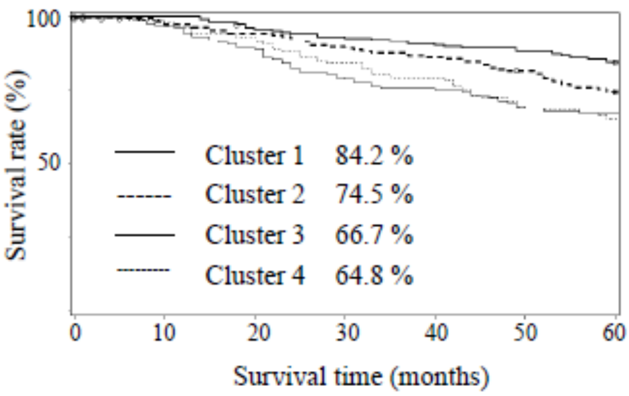

Figure 2. Five-year Breast Cancer Survival Rates

Discussion

In this study, we analyzed the characteristics of RT resources in Osaka and their effects on breast cancer patient prognosis using linked datasets.

Based on the results of principal component analysis, 11 items, including personnel, equipment and treatment performance items, were extracted as RT resource indices. Personnel items consisted of various resources such as "Number of full-time ROs", "FTE of full-time ROs", and "Number of full-time radiological diagnosticians", which were analyzed to determine the importance of these resources for RT. In addition, diagnosis equipment items extracted included the "Number of X-ray and CT scanners", "Number of MRI scanners", "Number of LINAC devices", "Number of radiological beds" and "Number of beds". The LINAC is a standard installment at RT facilities and therefore its index did not vary as a treatment resource. The proportion of the contribution by LINAC's was lower than for X-ray and CT scanners. This result might reflect the fact that a normal medical institution includes X-ray and CT scanners which are set up for diagnosis, while a medical institution in which multiple devices are set up often includes equipment used for RT. It was shown that important RT resources consisted not only of treatment equipment but also of diagnostic equipment in the radiology department, as well as beds.

Currently in Japan, there is an overwhelming lack of RT personnel 2). Medical physicists are specialists that manage the quality of treatment to ensure that proper RT is performed. RT guidelines produced from a report from the European Society for Therapeutic Radiology and Oncology (ESTRO) recommend one LINIAC per 450 patients, one ROs per 200-250 patients, and one medical physicist per 450-500 patients or per LINAC (Sltoman BJ et al, 2005). In all the medical institutions in Osaka, Japan, however, only a few medical physicists are employed. Personnel conducting such quality management are important from the perspective of preventing medical accidents. For maintenance of infrastructure and personnel at RT facilities, it is desirable that the standard of treatment resources in Osaka agree with the ESTRO guidelines. It is also desirable that "the number of medical physicists" becomes part of the main element composition of treatment resources pertaining to maintenance.

Cluster analysis of RT facilities using 11 extracted items resulted in broad classification of 48 RT facilities into 4 clusters. RT facilities from clusters 1 and 2 were better equipped in infrastructure and personnel than clusters 3 and 4. Cluster 1 consisted primarily of University-affiliated hospitals, along with 2 designated cancer care hospitals. This indicates that the bulk of radiation treatments are conducted at University-affiliated hospitals. Other designated cancer care hospitals were classified as belonging to all clusters. This indicates that structural variability among designated cancer care hospitals exists even though they were set up with equalization of cancer care services in mind. From a RT perspective, designated cancer care hospitals that become equipped with practical treatment resources are then classified as belonging to cluster 1.

Treatment outcome based on 5-year survival rates were calculated for each cluster. Of the five largest cancer types in Japan (stomach, large intestine, liver, lung, breast), breast cancer was chosen as the target for this study, for which the standard treatment is surgery and irradiation.

After comparing 5-year survival rates for each cluster based on cluster analysis of RT facilities, patient prognosis was found to be relatively good in every cluster for patients with localized cancer. Breast cancer is characterized by excellent recovery rates, and in patients with localized disease where progression had not occurred, no difference existed in survival rates due to differences in treatment resources.

For breast cancer patients with regional disease, a difference in prognosis due to the size of the treatment resources was found to exist. There was an approximate 20% difference between cluster 1, which had the highest survival rate. Five-year survival rate decreased progressively from cluster 1 to cluster 4. This corresponds to the treatment resources in each cluster, indicating that differences in prognosis are associated with differences in treatment resources.

For breast cancer, determination of the survival rate beyond 5 years is desirable. However, the target data for this study required linkage to the JASTRO dataset, which was not available from the JASTRO database until the year 2003. In the OCR, since prognosis surveys are conducted only at 5 and 10 years, the 10-year prognosis survey data appropriate for linking to 2003 was not available. We therefore compared 5-year survival rates in this study. To determine the effect of treatment resources on breast cancer patient prognosis, it is best to analyze 10-year survival rates, however, in this study, even using 5-year survival rates showed a difference between clusters in the prognosis of cancer patients with regional disease. An additional limitation of this study is that the OCR database collects information regardless of whether each treatment had been undertaken or not. In the case of breast cancer, the treatment method altered from mastectomy to breast conserving surgery from the late 1980's. This study did not analyze details of the effect of the treatment method and preoperative irradiation or postoperative irradiation because detailed RT data was not present in the OCR database. The difference in survival rates might reflect a difference in treatment method. The amount of adjuvant treatment, chemotherapy, and hormone therapy undertaken was different between clusters, which indicates that the treatment method was not common for each medical institution. This may also have affected breast cancer survival rates.

Maintaining the treatment resources of RT facilities is an important issue in Japan, where cancer is the leading cause of death. The 11 treatment resource indices effectively classified 48 RT facilities in Osaka and demonstrated a difference in breast cancer survival rates. We plan to repeat this analysis for other types of cancer that utilize RT, including prostate and cervical cancers. Whether similar trends are observed in regions outside of Osaka is another question that needs to be resolved. In the future we are also planning to examine practical effects of the number of treatment devices and personnel resources.

In conclusion, eleven items from the JASTRO database were chosen as treatment resource indices for improving RT facilities. According to treatment resource characteristics, RT facilities in Osaka were classified into 4 clusters. The supplemental need of personnel resources was investigated. The difference in treatment outcomes and 5-year survival rates may be associated with inadequate treatment systems in RT facilities.

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